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Sub-MeV Ion Fluxes and Anisotropies Measured Aboard ISEE-3 from 1978 to 1982

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Abstract

From 1978 to 1982, the DFH-EPAS experiment aboard the ISEE-3 spacecraft measured suprathermal and energetic ion fluxes and their directional distributions in 8 energy bins near the L1 libration point, in the energy range 35 keV to 1.6 MeV. The energy dependence of sunward streaming in the solar wind frame was examined for several quiet-time periods, and a very pronounced sunward streaming was found below about 200 keV (Rodríguez-Pacheco et al., 1998). In fact, at about 100 keV the sunward streaming in the wind frame was found so strong that the particle population appeared much more isotropic in the spacecraft frame than in the solar wind frame, showing only a slight convective dragging by the wind.. Such a directional distribution might result e.g. from the contamination of low counts by a relativistic particle population. The study has now been extended to check the correlation of the streaming with flux levels for the whole period spent at L1 (more than 30,000 hourly data), and we also investigated the distribution of flux levels, particularly in the low-flux region. No clear-cut evidence for contamination has been found.

1 Experimental Setup

The experiment "DFH-EPAS" onboard the ISEE-3 spacecraft (Balogh et al., 1978, van Rooijen et al., 1979) consists of three identical semiconductor telescopes designated T1, T2 and T3, each with a conical field of view of half-angle 16º, and a geometrical factor of 0,05 cm^2 sr. The detector viewing directions are inclined by 30º, 60º and 135º with respect to the spacecraft spin axis, which is directed northward, perpendicular to the ecliptic plane. The energy range of the instrument is divided into eight logarithmically spaced energy channels (E1,...,E8) with their lower thresholds at 36, 56, 91, 147, 238, 384, 612 and 1000 keV. The directional information for every energy channel was obtained in eight equi-angular (45º, except for E8: 90º) azimuthal sectors (S1,...,S8). In this work, only data from telescope T2, pointing at 30º above the ecliptic plane, have been used.

2 Data Evaluation and Preliminary Results

In the preliminary results presented recently by Rodríguez-Pacheco et al., (1998), the directional distributions were worked out for 17 quiet-time periods with a total duration of 545 hours, partly selected for study by Wenzel et al. {1990). For every energy channel and for every period, the anisotropy was "quantified" by the "Average Intensity Vector" (AIV). This AIV was worked out by adding the intensity vectors associated with every sector. It is defined in the following way: for every sector, the amplitude (or absolute value) of its intensity vector is the averaged intensity, expressed in particles/(cm^2 s sr keV), measured over the whole period, and its direction and sense are those defined by the pointing direction of the particular sector (i.e. sunward for S1, and anti-sunward for S5). Thus from the intensity vectors the AIV was worked out in such a way that its amplitude characterizes the first order anisotropy (A1), and its direction and sense indicate the direction and sense of the incoming particles.

As the Compton-Getting effect is expected to cause a large anisotropy in the spacecraft frame at low energies, the AIVs for the 17 quiet-tiime periods were calculated in both the spacecraft frame (SC) and in the solar wind frame (SW). When performing the frame transformation, both the solar wind velocity and the spectral indices associated with the events were used. The reduction due to the 30º inclination of telescope T2 was also taken into account.

The AIV vectors associated with channels E1, E3, E5 and E7 were plotted in Rodríguez-Pacheco et al. (1998). In the spacecraft frame the directional distribution appears nearly isotropic, while in the solar wind frame a sunward streaming of particles is apparent, which tends to increase with decreasing energy.

The effect is persistent and it becomes quite conspicuous when the AIVs are averaged over the 17 QT periods. The first order anisotropy values reach a maximum of 0.98 for the lowest energy channel (36-56 keV), and a minimum of 0.24 for channel E7 (612-1000 keV). The plot of phases also indicates strong sunward streaming.

In summary, the study of the spatial distributions of energetic particles during QT shows that in the solar wind frame there is a substantial stream of particles with energies below 200 keV, coming from the antisunward direction. A sunward streaming is in fact not quite unexpected if energetic particles are predominantly accelerated beyond 1 AU in interplanetary space, and could come from the seed population closely connected with the solar wind high-energy tail. At around 1 MeV, the effect appears also consistent with the findings of Marshall and Stone (1978). We discard a magnetospheric source because spectral indices involved are lower than those associated with magnetospheric events, and magnetic connection to L1 is poor.

3 Further Checks and Results

The quiet-time periods considered above constitute a minor fraction (less than 2 %) of the total time spent by ISEE-3 in the vicinity of the L1 point. It has been considered worthwhile to have a closer look at the statistical behaviour of anisotropies and flux distributions in this much larger data set. As solar wind and magnetic field data are also available for at least some fraction of the time, cross-correlations and joint distributions are also of interest. ISEE-3 and in particular DFH-EPAS data still hold a lot of information, and it can only be hoped that the full-resolution data sets can be restored from old tapes and studied again in full detail.

First we checked whether the small SC-frame anisotropies were true only for the contiguous QT periods selected earlier, or were also valid for all low-flux data. The result is that the amplitude of the anisotropy is definitely decreasing with decreasing flux levels for each of the 8 energies, and there is hardly any SC-frame anisotropy at the lowest flux levels. Although a slight outward streaming is seen at all energies, it is almost an order of magnitude less than what would be expected from the Compton-Getting effect. As an inward streaming relative to the solar wind that almost exactly compensates for the effects of convection may appear unlikely, one first suspects some background coming from high-energy (relativistic) particles. Such a background is expected to show up when one plots the differential flux distribution, i.e. the numbers (or frequencies) of hourly periods with given binned fluxes (or log-fluxes). Above energies of several MeV, a sharp peak usually shows up in such plots at the relatively stable level of cosmic ray intensity at the nominal energy. When the anticoincidence cup of a detector is not operating, a similar peak appears, giving the level of high-energy cosmic rays affecting the low-energy detector.

Figure 1 shows some of the frequency distributions of the logarithmic fluxes (or log-fluxes), calculated from the whole period of 4.5 years spent by ISEE-3 in the vicinity of L1. In each decade of flux, 100 logarithmically spaced bins are given, and the numbers on the left-hand axis represent the number of hourly periods belonging to a particular flux bin. No sharp peak appears, although there is a very sharp cutoff on the low-flux side, particularly for the lowest energies (e.g. for channel 1). We have no obvious explanation for such a behaviour.

In Figure 2, we present the cumulative or integral distributions for all 8 energy channels of the DFH detector. It is remarkable how regularly the curves behave. Energy spectra are typically also found to be fairly smooth power laws, without distortions expected from substantial background contributions.

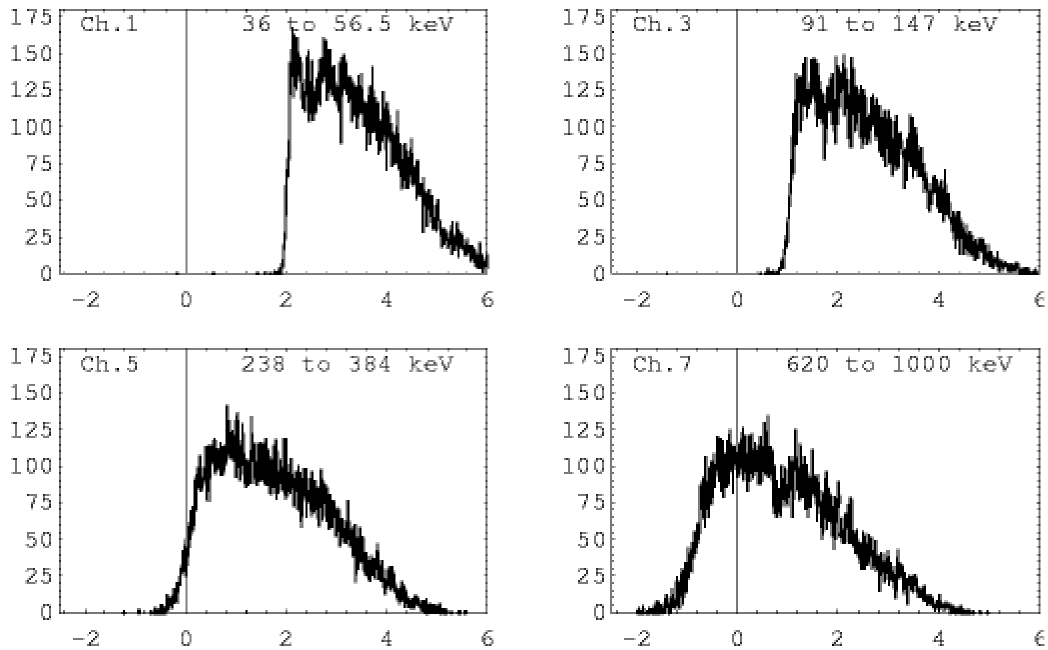

Figure 1. Frequency distributions of logarithmic fluxes for the whole period of 4.5 years spent by ISEE-3 in the vicinity of L1. In each decade of flux, 100 logarithmically spaced bins are given, and the numbers on the left-hand axis represent the number of hourly periods belonging to a flux bin.

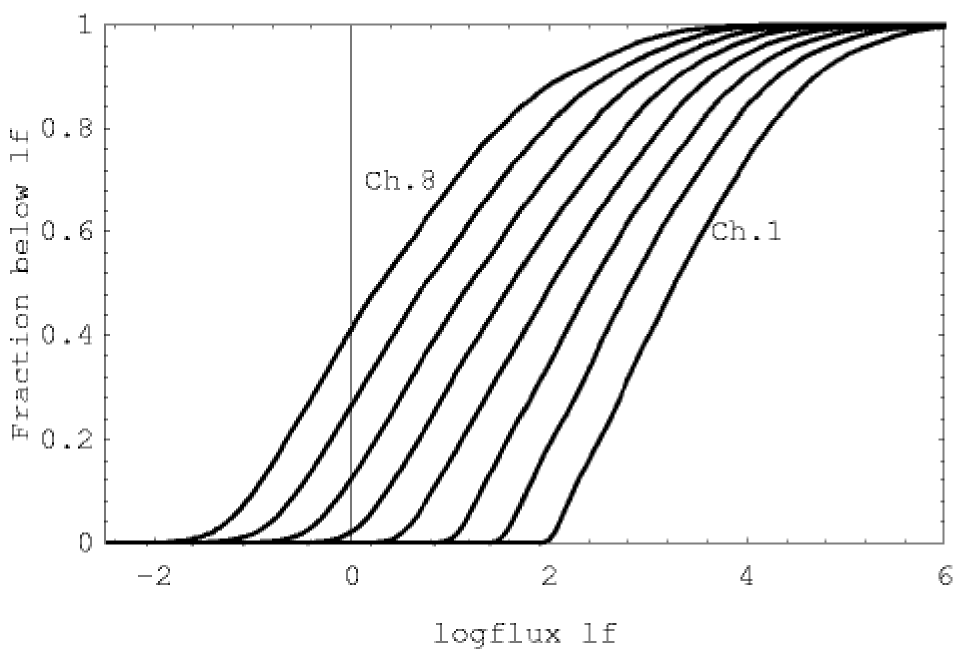

Figure 2. Integral logarithmic flux distributions of ISEE-3 DFH fluxes in the same period as above. Curves are remarkably smooth and regular. Energies of channels increase from right to left.

4 Conclusions

ISEE-3 DFH/EPAS results on the anisotropy of sub-MeV ions at low-flux periods are puzzling. They indicate much less streaming in the spacecraft system than would be expected from the Compton-Getting effect, if the population is convected by the solar wind. We do not exclude a possible very smoothly changing contamination by high-energy cosmic rays or neutrals in our results. Nevertheless, if we accept the calibration and simulation results of the paper of van Rooijen et al. (1979) that has already been mentioned, the contamination should be small, and the explanation for the small SC-frame anisotropy is still missing.

Acknowledgements

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